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Renewable energy potentials in Nigeria: Meeting rural energy needs

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ABSTRACT

Nigeria is endowed with abundant energy resources, both conventional and renewable, which can potentially provide the country with a sufficient capacity to meet the ambitions of both urban and rural Nigerians of a full, nationwide electrification level. Yet, Nigeria has one of the lowest consumption rates of electricity per capita in Africa. With the demand superseding the generation, there is inequitable access of rural communities to the electricity service in the country. There are inherent obstacles militating against the effective implementation of an orderly energy policy in Nigeria. The inefficiencies overshadowing the allocation of energy resources coupled with the near depletion of fossil fuels, make it imperative for the country to exploit its huge natural renewable resources to avoid a worsening energy supply scenario and provide feasible electricity to rural dwellers. This paper presents a review of renewable energy potentials in Nigeria to be tapped for useful and uninterrupted electric energy supply. The extent of renewable energy resources is described and existing government policies are articulated. Various polices, that could possibly incentivize the realization of wider renewable energy applications in rural Nigeria, are proposed. The challenges and future prospects of renewable energy are also discussed. Dissemination of decentralized renewable energy resources will not only improve the wellbeing of rural Nigerian communities, but also enhance Nigeria's energy and economic prospects for potential global investment.

Contents

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1. Introduction

Nigeria is located in West Africa, bordered by Cameroon to the east, Niger to the north, Benin Republic to the west and the Atlantic Ocean to the south. The terrain varies from coastal swamps and tropical forest in the south, to savannah and semi-desert in the north. Nigeria lies within latitudes 4.32°N and 14°N and longitude 2.72°E and 14.64°E as shown in Fig. 1, with land area of about 924,000 km^2 and a population of 165 million [1,2].

Nigeria is richly blessed with reasonably high qualities of various energy resources [3], such as crude oil, tar sands, natural gas and coal. About 90% of the country's economy is dependent on crude oil [4]. In 2006, Nigeria was ranked the 10th largest crude oil producer in the world with a reserve estimated to be about 36 million barrels, which is about 4.9 billion ton of oil equivalent (toe) [4]. The country is endowed with more of natural gas than oil, with an estimation of 5210 billion m^3 (187 trillion SCF) as of 2006. This includes associated and non-associated reserves; placing Nigeria among the top 10 countries with the largest gas reserves globally [1]. Nigeria also possesses other energy sources including 4.1 billion toe of tar sands and 1.52 billion toe of coal and lignite. However, it has been estimated that Nigeria's fossil fuels will be depleted to an uneconomical point by the year 2050 [3]; going by the present extraction trend. Moreover, Nigeria, surprisingly, imports over than 70% of its petroleum product requirements [3].

Nigeria is equally blessed with renewable energy (RE) resources like wind, solar, biomass and hydropower [5]. Hydropower has the utmost RE potential, which amounts to 10,000 MW for large hydropower and 734 MW for small hydropower (SHP). Further RE sources include wind energy with a potential of 150,000 terra joule per year, generated by an average wind speed of 2.0–4.0 m/s, solar radiation estimated at 3.5–7.0 kWh/m^2, and biomass at 144 million ton per year [6]. However, these resources are yet to be explored.

Despite the abundance of energy resources available, Nigeria is only able to generate 1600 MW effectively out of 6000 MW of installed generating capacity (less than 30%). This is because most of the power grid facilities are poorly maintained. Nigeria's power sector retains high energy losses, between 30% and 35%, from generation to billing. This is significantly high as compared with the US, where power losses across lines usually come to less than 7%, even across long distances [7]. In addition, there is a low collection rate, 75–80%, and low access to electricity by the population. Since there is insufficient cash generation, because of these inefficiencies, the Power Holding Company of Nigeria (PHCN) is consequently reliant on fuel subsidies and state funding of capital projects. Declining electricity generation from a number of domestic power plants has sent the country into an energy crisis during 2000/2001. Currently, the actual electricity

Fig. 1. Map of Nigeria.

Table 1
Nigeria Conventional Energy Resources and its Potentials.
Source: Renewable Energy Master Plan (2009).

Resource type	Reserves		Production	Domestic Utilization (natural units)
	Natural units	Energy units (Btoe)		
Natural gas	187 trillion SCF	4.19	6 billion SCF/day	3.4 billion SCF/day
Crude oil	36.22 billion barrels	5.03	2.5 million barrels/day	450,000 barrels/day
Tar sands	31 billion barrels of equivalent	4.31	Insignificant	Insignificant
Coal & lignite	2.175 billion ton	1.52	–	–
Nuclear element	None	–	–	–

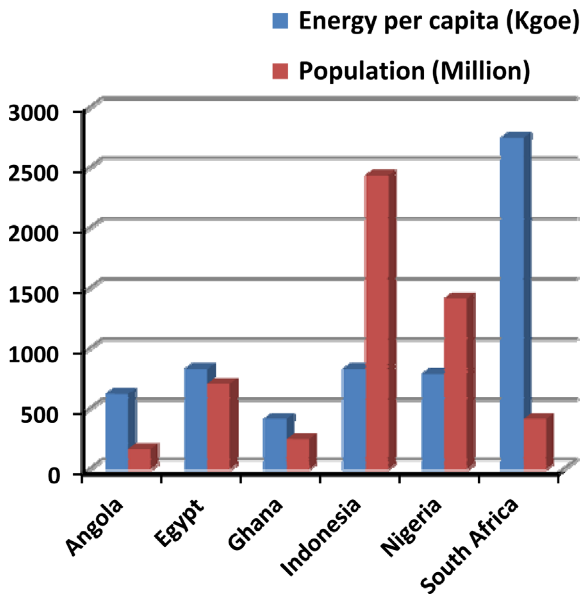

Fig. 2. Energy per capita of some selected countries.

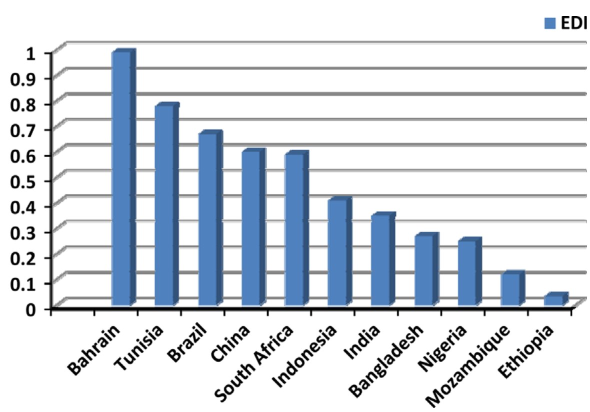

Fig. 3. Energy development index ranking of some selected countries.

generation of the country is considerably below the demand for electrical energy.

Majority of the Nigerian citizens are rural dwellers where there is difficult terrain, no easy access to fossil fuel and electricity grids because of bad roads. Most of these communities are located at a reasonably long distance from the nearest common connection point of a utility grid system. Some of the rural communities have very low population density and are characterized by low level of education, and low load density. The latter is usually identified by very short periods of peak load. The rural dwellers resort to the use of diesel generators for electricity. However, several factors affect the smooth operation of their diesel generators. Apart from the high cost of fuel and maintenance, other constraints include non-availability of access/good roads most especially during the rainy season, when the roads are flooded for several days hindering delivery of the necessary fuel and other materials needed for the running of the generator [8]. More so, it is not possible to run a generator for 24 h daily. This results in the use of kerosene lamps, candles and the likes, thus spending so much time collecting fuelwood for cooking/heating purposes. Moreover, these rural communities have no proven deposits of crude oil, natural gas or large body of water. Nevertheless, they are blessed with abundant RE resources such as solar radiation, biomass, wind speed and sometimes, small rivers for small hydropower (SHP) production [9].

At present, only 10% of rural households and 40% of the country's total population have access to electricity. The Nigerian Energy Commission and the Solar Energy Society of Nigeria have been tasked with generating a standalone solar-powered solution for the remote rural dwellers. The country is looking towards further development of the hydropower resources and other renewable energies such as wind, solar and biomass to close the generation shortfall and foster the economic growth. The level of utilization of Nigeria's RE resources requires serious attention to salvage the country from a looming energy crisis.

This paper examines the potential of renewable energy resources in Nigeria that can be harnessed for continuous energy supply, most especially in rural areas. The paper is organized as follows. Section 2 enumerates the present state of conventional generation in Nigeria. Section 3 discusses the existing potentials of the RE resources. The government energy policies are outlined in Section 4. A set of proposed measures and policies that can effectively advance RE in Nigeria is spelled out in Section 5, while Section 6 highlights the prospects of RE for rural energy provision. Finally, Section 7 provides the conclusions.

2. Status quo of conventional energy in Nigeria

Energy resources are among the most important assets of any nation. It is a well known fact that high rate of industrial growth is a function of the amount of energy available and the extent to which that energy is utilized. Africa's electricity consumption from 1980 to 2001 grew on the average by 3.1% per year. Africa's per capita demand for electricity declined compared to the ones achieved in North America and the Middle East; making Africa the region with the smallest per capita consumption of electricity in the world [10].

Nigeria has substantial energy resources, including over 4 billion metric tons of coal and lignite, 187 trillion ft^3 of gas and 36 billion barrel of oil [11], as shown in Table 1. Oil, however, remains the dominant fuel source for electric energy production. In 2005, oil contributed 57% to the energy mix of Nigeria, followed by 36% of natural gas and 7% hydroelectricity [12]. Energy is an essential ingredient for the economic growth, running existing industries, establishing new ones, rapid urbanization and achieving a higher standard of living. However, while oil and gas-rich Nigeria's electricity output in 2009 was 2000 MW, South Africa produced 43,000 MW of electricity for a population size that matches one third of Nigeria's [13]. On per capita basis, Senegal, Ghana, Gabon, Zambia, Algeria, Mozambique, Cameroun and Libya were generating more electricity than Nigeria's [13]. Fig. 2 shows that Nigeria's consumption of electric power per capita ranked among the least of some selected countries. Moreover, Nigeria's energy development index (EDI) [14] depicted in Fig. 3, indicates that there is a categorical size of the population who do not have access to electricity. On the other hand, Fig. 3 also shows that South Africa has significantly higher per capita consumption rate than the region's other countries. In fact, it generates 2/3 of Africa's electricity and consumes an absolute majority of the electricity used in Africa [15].

The current output of 4420 MW and the medium target of 13,000 MW by 2013, looks untenable compared to a projected demand of 26,561 MW by 2020 [13]. The level of energy consumption in Nigeria is alarmingly low compared with other countries with corresponding energy resources and population sizes, despite being Africa's most populous country, retaining large reserves of energy resources.

While Nigeria's electrical energy demand is high, its actual generation is considerably below demand. With a projected rate of fossil fuel depletion in 40 years and potentially devastating

environmental problems associated with its use, it is imperative for the government to explore alternative energy resources. At present, nuclear energy, renewable energy, and even coal energy have no noticeable role in Nigeria's energy mix. Therefore, there is an urgent need to tap Nigeria's huge natural renewable energy resources to evade stumbling into an energy supply crisis [12].

3. Renewable energy in Nigeria

The global mindfulness of the phenomenon of climate change together with the anticipated scarcity of conventional energy resources have prompted many countries around the world to develop a more sustainable energy systems to cater for development and growth. Renewable energy provides a safe and feasible option for the provision of a clean and environment friendly energy. Demographic change, dramatic population increase and industrial growth are part of the major trends coming up in Nigeria. In line with broad international consensus and the policies of most developed countries to embrace RE resources as a better source of energy, the Government of Nigeria (GoN) had to rethink its own energy policies. There exists a vast biomass potential in the form of biocrops and fuelwood, biogas, wind, solar and small hydro in Nigeria, albeit being grossly underutilized. As observed in quite a number of successful countries in promoting RE such as Denmark, Germany, USA, China and Japan, a strong and long-term commitment from the government is crucial in implementing any kind of policies which will lead to efficacious RE development [16].

About 90% of the energy used by rural dwellers in Nigeria comes from fuelwood [17]. It is derived from non-nuclear and non-fossil sources in a way that can be replenished while harvesting. Conversion and use of fuelwood from these sources take place in a way that helps to avoid negative effects of deforestation on the viability and rights of rural dwellers and natural ecosystems [18]. Apart from fuelwood, a major means through which greenhouse gases (GHGs) are emitted into the atmosphere is the practice of gas flaring by oil companies operating in the country. Nigeria is one of the highest producers of GHG emissions in Africa [19]. Carbon dioxide (CO_2) emissions in the country are among the highest in the world [19]. Some 45.8 billion kW of heat are discharged into the atmosphere of the Niger Delta, Nigeria from flaring 1.8 billion ft^3 of gas everyday [19]. Gas flaring has increased the temperature and made some areas to become inconvenient to live in. A total of about 125.5 million m^3 of gas were produced in the Niger Delta between 1970 and 1986, in which 102.3 million m^3 were flared while only 2.6 million m^3 was used as fuel by oil producing companies, and about 14.6 million m^3 were sold to other consumers [20]. Overdependence on the burning of fossil fuel can be obviated by the use of RE sources. Moreover, the flared gasses can be converted to methanol and used as fuel for both industrial and domestic purposes.

Environmental degradation, unstable oil prices in the international market, global warming, and the social crisis in the Niger Delta area, where the bulk of Nigeria's crude oil is extracted, have further made the choice of RE inevitable [21]. The potential of RE in Nigeria is about 1.5 times that of fossil energy resources; in energy terms [22]. Hydro, solar, biomass and wind have significant potential to improve and make a difference on the low level access of electricity in Nigeria. The sources, capacity and potential of each RE resource, shown in Table 2, are discussed below.

3.1. Hydroelectric energy

To facilitate continuous energy supply globally through RE sources, hydropower generation stands as a one potent option to meet the growing demand of energy. The world hydropower capacity in 2004 was 2810 TWh and is projected to be 4903 TWh by the year 2030, with 1.8% growth rate per year, though the share will remain at 2% of the world energy supplied [15]. A large number of global hydropower development projects with a total capacity of about 100,000 MW are currently going on. The greatest contribution is coming from Asia at 84,000 MW. The contribution from other regions are: South America 14,800 MW, North and Central America 1236 MW, Europe 2211 MW and Africa 2403 MW [23].

Hydropower is conceivably regarded as the major source of electric power generation and supply in Nigeria because the country is endowed with large rivers, waterfalls and dams. Only large hydropower technology is the prominent commercial RE technology in the electricity supply mix of the country. Due to economy of scale, large hydropower technology takes the lion share of the entire commercial RE resources for electricity generation under any CO_2 emission constraints [24]. Unlike fossil fuel, hydropower is renewable and can supply uninterrupted fuel, except for the question of water levels. The total potential of hydropower in Nigeria is about 14,750 MW. However, only 1930 MW, approximately 14%, of that is currently being generated at Shiroro, Kanji and Jebba representing about 30% of gross installed grid-connected electricity generation capacity of Nigeria

Table 2
Renewable energy resources.
Source: Renewable Energy Master Plan (2009).

Resource type	Reserves			Production	Domestic utilization (natural units)
	Natural units		Energy units (Btoe)		
Small Hydropower	3500 MW		0.34 (over 40 years)	30 MW	30 MW
Large Hydropower	11,250 MW		0.8 (over 40 years)	1938 MW	1938 MW
Wind	2–4 m/s at 10 m height (main land)		0.0003 (4 m/s @ 12% probability, 70 m height, 20 m rotor, 0.1% land area, 40 years	–	–
Solar Radiation	3.5–7.0 kWh/m^2/day (4.2 million MWh/day using 0.1% land area)		5.2 (40 years and 0.1% land area)	6 MWh/day	6 MWh/day
Biomass					
Fuel wood	11 million hectares of forest and wood land	Excess of 1.2 m ton/day	–	0.120 million ton/day	0.120 million ton/day
Animal waste	211 million assorted animals			0.781 million ton of waste/day	None
Energy crops and agric residue	28.2 million hectares of arable land (≡30% of total land)			0.256 million ton of assorted crops/day	None

[25]. This assessment is for large hydropower, which was the type in operation before the 1973 oil crisis.

Hydroelectric energy in Nigeria is still underexploited in spite of its high capacity. In view of this, small hydropower (SHP) has gained rapid consideration in both the developed and developing economies of the world. This is due to the SHP inherent advantages such as reduced minimal civil works, environmental impact, unexcessive topology, and the possibility for power generation alongside with flood prevention, navigation, irrigation and fishery. As depicted in Table 2, about 734 MW of the SHP can be harnessed from 277 sites (based on a 1980 survey) [26]. The SHP potential is estimated at 3500 MW, representing about 23% of the whole country's total hydro potential.

Three of the states surveyed, Kano, Sokoto and Plateau have a total of 30 MW of SHP installed capacity in operation. In addition, 21 MW is being generated by the Nigerian Electricity Supply Company (NESCO) from six other sites in Plateau State. About 5% of the available SHP capacity is being exploited currently, whereas the rest is deferred for future development. Tables 3 and 4 show the SHP surveyed in the country and the existing SHP scheme in Nigeria. Out of the total capacity of 734.2 MW, only 32 MW were developed while 702.2 MW are yet to be developed. There is a vital need to develop these on time. More mini- and micro-hydropower schemes can be established across the country, to extend electricity provision to rural and remote areas.

Hydro capacity is largely dependent on the annual rainfall levels, with its distribution as well as the river systems; hence it is subject to seasonal drought. Total rainfall increases generally from about 500 mm depth in the northern part of the country with a total precipitation lasting over 3 months in a year to 3400 mm at the southern boundaries with a precipitation that may be less than 8 months annually [27].

The hydropower potential in Nigeria should be developed to its full extent to assist the country and reduce fiscal loads. Hydro energy does not only have the potency to close the gap between generation shortfall and load demand, but can also provide an excellent green source of energy to remote areas. The available small rivers in the rural communities could be developed into SHPs. Through this development, rural communities can be transformed into urban centers, various socioeconomic activities can be improved and the needs of the rural dwellers can be met in a sustainable way.

3.2. Solar energy

Solar energy can provide a cheap and abundant energy for communities whose connection to the national grid may not be economical due to their remote physical location from the nearest grid connection point. Solar energy is an alternative source of energy in rural and remote areas of Nigeria. It complements rapid development of small scale industries and reduces the rural–urban drift. The country receives abundant solar radiation and sunshine [1].

Solar energy is the most promising of the RE resources in Nigeria due to its apparent abundance [28]. Energy radiated from the sun is about 3.8×10^{23} kW, which is 1.082 million ton of oil equivalent (mtoe) per day [29]. This is about 4000 times the current daily crude oil production in Nigeria and about 13,000 times the natural gas daily production, based on standard energy units [30]. The total energy demand of the nation could be met if only 0.1% of the total solar energy radiant on Nigeria's land mass is converted at an efficiency of 1% [31]. Nigeria has an average of 1.804×10^{15} kWh of incident solar energy annually based on Nigeria land area of 924×10^3 km^2 and an average of 5.535 kWh/m^2/day. The sun shines on the average for 6.5 h/day. The annual solar energy value is about 27 times the country's total fossil energy resources in energy units and is over 115,000 times the electrical power produced [3]. Therefore, it means about 3.7% of Nigeria's landed area is required to collect an amount of solar energy equal to the country's conventional energy reserves. The monthly average global solar radiation in Nigeria for a period of 25 years is shown in Table 5.

Solar energy is also the primary energy resource driving other RE sources such as wind, biomass, wave and hydropower. Although the current solar energy installation in Nigeria is relatively insignificant compared with that of South Africa's, which already have more than 200,000 'off grid' installations of PV, Nigeria is just developing its capabilities to utilize solar energy

Table 4
Small hydro scheme in existence in Nigeria.
Source: Renewable Energy Masterplan (2005).

River	State	Installed capacity (MW)
Bagel I	Plateau	1
Bagel II	Plateau	2
Ouree	Plateau	2
Kuna	Plateau	8
Lere	Plateau	4
Lere	Plateau	4
Bakalori	Sokoto	3
Tiga	Kano	6
Total		30

Table 3
Small hydro potential in Nigeria.
Source: Renewable Energy Masterplan (2005).

State (Pre 1980)	River basin	Total sites	Hydropower potential		
			Developed (MW)	Undeveloped (MW)	Total capacity (MW)
Sokoto	Sokoto-Rima	22	8.0	22.6	30.6
Katsina	Sokoto-Rima	11		8.0	8.0
Niger	Niger	30		117.6	117.6
Kaduna	Niger	19		59.2	59.2
Kwara	Niger	12		38.8	38.8
Kano	Hadeija–Jamaare	28	6.0	40.2	46.2
Borno	Chad	28		20.8	20.8
Bauchi	Upper Benue	20		42.6	42.6
Gongola	Upper Benue	38		162.7	162.7
Plateau	Lower Benue	32	18.0	92.4	110.4
Benue	Lower Benue	19		69.2	69.2
Cross Rivers	Cross Rivers	18		28.1	28.1
Total		277	32	702.2	734.2

through its National Energy Policy (NEP). Countries like Japan, Germany and USA have promoted the interconnection of PV panels with the national grid through incentive programs, and their grid market is now far larger than the off grid market [16]. Nigeria has good radiation sites that can boost the development of solar energy, yet research efforts and government attention in that direction have yielded very little results. Effective policies need to be wielded to foster solar energy development in Nigeria.

3.3. Wind energy

Wind energy generation is the fastest growing renewable energy market worldwide. The global cumulative installed capacity of wind power gradually increased from 6100 MW in 1996 to 158,505 MW in 2009. At the end of 2014, wind energy will have over than 238 GW of installed capacity and is expected to play a crucial role in mitigating future GHG emissions [32]. Eighty two (82) countries are using wind to generate energy, and 49 countries have increased their installed capacity since 2009. Middle East and African countries have also recorded a total of 230 MW of newly installed capacity, with Morocco and Tunisia recording 90% and 170% growth rate respectively. Although, these values are small compared with wind energy producing regions like North America, Asia and Europe, the presence of wind energy in remote locations of the world simply highlights the continued rapid growth in global demand for emission-free wind power, which can be installed virtually anywhere around the world [32,33]. At the end of 2009, Egypt, Morocco and Tunisia are the leading countries in Africa with installed capacities of 430 MW, 253 MW and 54 MW respectively [33].

Wind speed in Nigeria ranges from 4.0 to 5.12 m/s in the extreme northern part of the country, while 1.4–3.0 m/s in the southern Nigeria; just like South Africa. The latter has a wind speed that ranges from 4.0 to 5.0 m/s for the majority of the coastal regions, but increasing approximately to 8.0 m/s in some mountainous areas [34–38]. This shows that wind speeds are generally weak in the southern part except at the coastal regions and offshore locations. A study carried out by the Energy Commission of Nigeria (ECN) reveals that total exploitable wind energy reserve at 10 m height may vary from 8 MWh/yr in Yola to 51 MWh/yr in the mountainous area of Jos, and could reach as high as 97 MWh/yr in Sokoto [39]. A potential estimate of wind speeds for 10 selected sites in Nigeria render the speed between 3.6 and 5.4 m/s [40]. These results when compared with the results obtained from calculated wind speed using Climatic Model Mainz, gives a discrepancy of −4.3% to 4.1%; which lies within the acceptable limit of error. The results of these 10 sites are presented in Table 6 and the estimated gross energy yield of the sites by wind turbine is shown in Table 7. High wind energy potentials for some selected states of Nigeria are depicted in Table 8. Assuming a medium generation capacity of 5 MW/km^2 (a) and 30% capacity factor (b), only 1% of effective wind area of these selected states has a potential to generate 50,046 MWh/yr of electricity [40,41]. Table 9 shows detailed potentials and wind energy densities at 25 m height, of 22 selected states of the country.

Nevertheless, with the promising gross energy yield and great potential for wind energy in Nigeria, wind prospecting is still in its infancy. Nigeria is yet to utilize wind energy potential for the betterment of its citizens, most especially the rural dwellers. In contrast, South Africa has utilized its wind power to energize water pumps with an estimated 30,000 systems installed [42]. Nigeria needs to take a step in the direction of Eskom, South Africa's electric utility company, which started to generate electricity from three wind turbines at the Klipheuwel site in 2002, with a view to investigating the potential of large-scale wind energy for bulk electricity generation [42].

Table 5
Maximum, minimum and yearly average global solar radiation (kWh/m^2/day) [4].

Stations	Location Lat. °N	Location Long °E	Altitude (m)	Max[a]	Min[b]	Monthly Average
Abeokuta	7.25	3.42	150	4.819	3.474	4.258
Abuja	9.27	7.03	305	5.899	4.359	5.337
Akure	7.25	5.08	295	5.172	3.811	4.485
Azare	11.8	10.3	380	6.028	5.022	5.571
Bauchi	10.37	9.8	666.5	6.134	4.886	5.714
Beni City	6.32	5.6	77.52	4.615	3.616	4.202
Calabar	4.97	8.35	6.314	4.545	3.324	3.925
Enugu	6.47	7.55	141.5	5.085	3.974	4.539
Ibadan	7.43	3.9	227.23	5.185	3.622	4.616
Ilorin	8.48	4.58	307.3	5.544	4.096	4.979
Jos	9.87	4.97	1285.58	6.536	4.539	5.653
Kaduna	10.6	7.45	645.38	6.107	4.446	5.672
Kano	12.05	8.53	472.14	6.391	5.563	6.003
Katsina	13.02	7.68	517.2	5.855	3.656	4.766
Lagos	6.58	3.33	39.35	5.013	3.771	4.256
Lokoja	7.78	6.74	151.4	5.639	4.68	5.035
Maiduguri	11.85	13.08	383.8	6.754	5.426	6.176
Makurdi	7.73	8.53	112.85	5.656	4.41	5.077
Minna	9.62	6.53	258.64	5.897	4.41	5.427
New Bussa	9.7	4.48	152	5.533	4.15	4.952
Nguru	12.9	10.47	342	8.004	6.326	6.966
Obudu	6.63	9.08	305	5.151	3.375	4.224
Oweri	5.48	7.03	120	4.649	3.684	4.146
Port Harcourt	4.85	7.02	19.55	4.576	3.543	4.023
Serti	7.5	11.3	610	4.727	3.972	4.488
Sokoto	13.02	5.25	350.75	6.29	5.221	5.92
Wari	5.52	5.73	6.1	4.237	3.261	3.748
Yola	9.23	12.47	186.05	6.371	4.974	5.774

[a] Average for the months of March, April and May.
[b] Average for the months of July and August.

3.4. Biomass

Biomass is an indirect form of solar energy because it arises due to photosynthesis. Fuelwood is the most common form of biomass energy. Nigeria is very rich in biomass resources such as wood, forage grasses and shrubs, wastes arising from forestry, agricultural, municipal and industrial activities, as well as aquatic biomass. The nation's biomass resources have been estimated at 8×10^2 MJ. Plant biomass can be used as fuel for small-scale industries. It could also be fermented by anaerobic bacteria to produce a very versatile and cheap biogas [43]. Apart from fuelwood, wood is equally used for paper products, sawn-wood, plywood and electric poles. Nonetheless for energy use, 80 million m^3 of fuelwood is utilized annually in Nigeria for cooking and other domestic purposes. The energy content of fuelwood that is been utilized is 6.0×10^9 MJ. Out of which only between 5% and 12% is profitably used for cooking and other domestic uses. Fuelwood and charcoal constituted between 32% and 40% of the total primary energy consumption over the period between 1989 and 2000. National demand was estimated to be 39 million ton of fuelwood in the year 2000. About 95% of the total fuelwood consumption was used in households for cooking and for cottage industrial activities such as for cassava and oil seeds processing. The availability of biomass as at 1973, was put at 9.1×10^{12} MJ [29]; however, the overall biomass available at present is ostensibly lower. The shortfall is a result of demand for wood used in construction and furniture industries, in addition to its uses as an energy source.

Estimates show that 200 million ton of dry biomass can be obtained from forage grasses and shrubs, releasing about 2.28×10^6 MJ of energy [12]. Majority of rural Nigerians depend on fuelwood for cooking and heating. Therefore about 350,000 ha of forest and natural vegetation are lost annually due to various factors, by the beginning of last decade, with a much lower

Table 6
Summary of measured data of annual wind speeds.
Source: Wind Energy Resources Mapping and Related Work Project: (LI/FMST, Nigeria, 2005).

Site	Land-use Type	Altitude (m a.s.l)	Height (m)	Wind speed (m/s)		Difference (%)
				Measured	KLIMM	
Enugu	Complex landscape	466	30	4.6	4.4	−4.3
Jos	Complex landscape	1344	30	5.2	5.1	−1.9
Pankshin	Complex landscape	1355	40	4.9	4.7	−4.1
Sokoto	Plain surface	352	30	5.4	5.2	−3.7
Kano	Plain surface	340	30	4.9	5.1	4.1
Gumel	Plain surface	393	30	4.1	4.2	2.4
Maiduguri	Plain surface	373	30	4.7	4.6	−3
Ibi	River valley	300	30	3.6	3.3	−8.3
Gembu	Highly complex landscape	1800	40	5	5.2	1
Lagos	Coastal area	2	30	4.7	4.9	4.3

Table 7
Gross energy yield.
Source: Wind Energy Resources Mapping and Related Work Project: (2005).

Site	Gross energy yield measurement (MWh)		
	Model FL 100, 100/20 Rotor dia. 21.0 m Hub height 34.5 m 100/20	Model FL 250, 250/50 Rotor dia. 29.5 m Hub height 42.0 m 250/50	Model V52, 850/52 Rotor dia. 52.0 m Hub height 44.0 m
Enugu	92.9	217.9	734.20
Jos	129.6	299	1025.80
Pankshin	117.1	272.1	936.60
Sokoto	153.5	358.8	1235.80
Kano	116.3	281.2	963.60
Gumel	73.4	197.2	681.40
Maiduguri	102.7	262.2	906.10
Ibi	49.8	141.3	481.20
Gembu	112.9	253.9	855.30
Lagos	129.3	386.1	1402.80

Model FL – Fulurander make of wind turbines. Model V – Vestas make of wind turbines.

Table 8
Estimated wind energy potentials.
Source: Nigeria Climate Assessment, LCD Power Sector, preliminary report (WBG/Lumina Decision Systems, 2011).

Selected State	**Area (km^2)**	**Windy Area (%)**	**Effective Wind Area (km^2)**	**1% Area (km^2)**	**Potential capacity a (MW)**	**Potential Generation b (MWh/yr)**
Adamawa	37,957	45	170,80	171	854	2244
Bauchi	48,197	50	24,098	241	1204	3166
Borno	72,767	100	72,767	728	3638	9561
Gombe	17,428	100	17,428	174	871	2290
Jigawa	23,415	100	23,415	234	1170	3076
Kaduna	44,217	60	26,530	265	1326	3486
Kano	20,389	90	18,350	184	917	2411
Katsina	23,822	100	23,822	238	1191	3130
Kebbi	36,320	25	9080	91	454	1193
Plateau	26,539	90	23,885	239	1194	3138
Sokoto	32,146	90	28,931	289	1446	3801
Taraba	58,180	40	23,672	237	1183	3110
Yobe	44,880	100	44,880	449	2244	5897
Zamfara	33,667	80&	26,933	269	1346	3539
Total				3809	19,043	50,046

Table 9
Wind energy estimates at 25 m height.
Source: Nigeria Climate Assessment, LCD Power Sector, preliminary report (2011).

Site	Mean wind speed at 25 m level (m/s)	Monthly mean wind energy (kWh)	Annual wind energy (kWh)	Annual wind energy from a wind turbine (kWh)	
				10 m blade diameter	25 m blade diameter
Benin City	2.135	2.32	27.86	2,18.81	13,673.78
Calabar	1.702	1.12	13.42	1.053.69	6587.53
Enugu	3.372	7.83	93.91	7375.75	46,097.96
Ibadan	2.62	4.15	49.78	3909.70	24,436.19
Ilorin	2.078	1.23	14.73	1157.06	7230.57
Jos	4.43	16.05	192.64	15,129.60	94,559.98
Kaduna	3.605	9.91	188.88	936.81	58,355.08
Kano	3.516	8.57	102.86	8078.61	50,491.28
Lagos (Ikeja)	2.671	4.36	52.32	4099.78	25,682.52
Lokoja	2.235	2.6	31.21	4451.23	15,320.17
Maiduguri	3.486	8.42	101.01	7933.61	49,583.17
Mina	1.589	1.05	12.60	989.60	6185.01
Makurdi	2.689	4.44	53.27	4183.51	26,148.85
Nguru	4.259	14.48	173.74	14,645.19	85,284.42
Oshogbo	1.625	1.07	12.81	1006.60	6288.09
Port Harcourt	2.64	4.17	49.98	3925.48	24,533.88
Potiskum	3.636	9.44	113.25	8894.35	55,591.46
Sokoto	4.476	16.47	197.68	15,525.75	97,035.94
Warri	2.027	2.02	24.20	19,00.66	11,879.15
Yelwa	3.36	7.76	93.13	7314.88	45,714.59
Yola	1.824	1.45	17.34	1.361.88	8511.75
Zaria	2.891	5.32	63.88	5, 017.26	31,357.02
Total		134.23	1680.50	120, 078.90	790,548.39

afforestation rate of 50,000 ha per annum [44]. The consequence is continuous felling of trees, which if left unchecked will result in ever increasing problem of desert encroachment and soil erosion. Therefore, the use of fuelwood needs to be discouraged through the introduction of affordable and acceptable solar stoves. This will reduce fuelwood consumption through better combustion and through a reduction in heat losses. It will equally reduce the cooking time as well as providing an organized channel for the exit of smoke [45]. Table 10 shows different biomass resources and their estimated quantities in Nigeria [44].

Biomass is certainly a key RE source, but the sustainability of its production needs to be clearly understood. Nigeria which has abundant biomass resources just like South Africa and Malaysia (which has similar weather, vegetation and at similar equatorial disposition with Nigeria) should make use of its oil palm products, woods, municipal waste, rice and sugar cane husk for biogas energy production. Most especially, sugar mill companies in the country can make use of their cane residues and waste, while paper and packaging mills can use waste biomass to generate process steam, as it is done in Malaysia and South Africa. This biomass energy could be converted to liquid fuel for cooking rather than fuelwood, thus reducing GHG emissions remarkably.

3.5. Biogas

Biogas is produced from the bacterial decomposition of organic matter in the absence of air, by the biodegradation of organic material under anaerobic conditions. Some of the biogas raw materials are animal dung, industrial wastes, household wastes

Table 10
Biomass resources and estimated quantities in Nigeria.

Resources	Quantity (million ton)	Energy value (000 MJ)
Fuelwood	39.1	531.0
Agro-waste	11.244	147.7
Saw dust	1.8	31.433
Municipal solid waste	4.075	–

and air dry crop residues. The mixture of different types of wastes produce more biogas energy [46].

Biogas is practically suitable for a variety of applications in the agriculture, household and industrial sectors. Its utilization instead of diesel, fuelwood, charcoal, and kerosene reduces GHG emissions. In addition, it exhibits no risk to health; does not have offensive odor and it burns with a clean bluish, spotless flame thereby making it non-messy to cooking utensils and kitchens [47].

Identified feedstock substrate is considered an economically feasible biogas program in Nigeria that includes dung, water hyacinth, cassava leaves, solid (including industrial) waste, water lettuce, urban refuse, agricultural residues and sewage [48]. Nigeria produces about 227,500 t of fresh animals daily and 20 kg of municipal solid wastes per capita is produced annually [49]. About 0.03 m^3 of gas can be produced from 1 kg of fresh animal wastes, thus, Nigeria can produce 6.8 million m^3 of biogas/day. Biogas production will not only increase the energy production but will also lead to a profitable means of reducing, if not eliminating, the menace and nuisance of urban waste.

Biogas is not yet listed in the energy mix in Nigeria. However, a research conducted in Ref. [50], shows that a 6.0 m^3 of family-sized biogas digester can generate 2.7 m^3 of biogas/day to satisfy the cooking need of a family composed of 9 persons. The project was estimated to have an initial cost of US $500 (equivalent to Nigerian Naira (NGN) 80,100), annual expenditure of NGN 11,200 and an annual benefit of NGN 25,600 [50]. Although the financial analysis of the project suggests that it has a good economic potential, its initial cost may make it unaffordable to majority of its intended users – the low income earners (mostly rural dwellers). Unless some measures are taken to bring down the capital cost or economically aid its targeted users, the objective of making biogas to penetrate into the low-income households may be, ultimately, defeated [47].

Countries like China, Kenya and India hold world records in the development and use of improved woodstoves. However, in spite of all these international breakthroughs, widespread development and dissemination of improved woodstoves is still not a reality in Nigeria [51]. The fact that the technology is relatively inexpensive and locally attainable has proven not to have enough incentive for a complete take-off in the country. The government of Nigeria (GoN) is therefore encouraged to enact a biogas bill backed by some legislation, which incorporates incentives and appropriate commercial terms for the use of biomass fuels. The GoN is also required to introduce efficient wood-burning stoves in rural areas at subsidized rates, and provide commercial market incentives to encourage the use of biogas digesters in order to cater for the cooking energy needs. This is important especially for households and institutions like boarding schools, hospitals, barracks, prison houses, etc.

Regrettably, renewable energy resources are presently disregarded from the energy supply mix in Nigeria, and yet have a modest share in future energy plans, albeit having a remarkable potential. This may lead to a risky situation of falling into a fossil fuel trap. With the near depletion of the fossil fuels in Nigeria, the prospect of sliding into a severe energy crisis seems inevitable. RE, therefore, stands out to be the key solution to an imminent energy crisis in Nigeria. Furthermore, it is the one and only gateway to energy provision in rural communities. Mini- and micro-hydropower, solar PV, biomass and wind energy should be utilized to extend electricity supply to rural and remote areas.

Renewable energy is also capable of alleviating the already over stretched ecosystem and supplying the energy required for rapid development, especially by encouraging the establishment of small-scale industries and by reducing migration from the rural to urban centers. Effective harnessing of RE technologies, to supplement energy produced from fossil fuel resources, would raise the reliability of electricity supply, cut back on carbon dioxide emissions, reduce energy insecurity, offset fossil fueled grid electricity, enhance availability of energy for socioeconomic activities and improve the standard of living of Nigerian citizens [28].

4. Energy policy

A comprehensive and coherent energy policy is essential in guiding a country towards the efficient utilization of its energy resources. It must be stressed that while the existence of an energy policy is crucial, it does not guarantee the prudent responsibility management of a country's energy resources.

4.1. National energy policy

Nigeria had no comprehensive energy policy until recently, when the energy policy in Nigeria was approved by the GoN in 2003. The policy was dubbed the National Energy Policy (NEP) with an overall objective of the optimal utilization of the nation's energy resources; both fossil and REs, for sustainable development and with the active participation of the private sectors.

The NEP articulated, amongst other things, that [52]

- extensive crude oil and natural gas exploration and development shall be pursued with the view to increasing their reserves base, to the highest level possible;
- the country shall continue to engage extensively in the development of electric power with the view to making reliable electricity available to 75% of the population by 2020; as well as to broaden the energy options for generating electricity.

Nigeria Electric Power Authority (NEPA), now the Power Holding Company of Nigeria (PHCN) in the energy policy of 2003, outlined a plan to diversify its energy sector and pursue RE. Table 11 shows the plan with regards to each energy form.

The mandate of the Energy Commission of Nigeria (ECN), an agency for the development and promotion of RE technologies in Nigeria, includes strategic energy planning, policy coordination and performance monitoring for the entire energy sector. Furthermore, laying down guidelines for the utilization of energy types for specific purposes and developing recommendations on the exploitation of new sources of energy. RE is therefore a component of its mandate [52]. The key elements in the national policy position on the development and utilization of RE and its technologies are as follows:

- to develop, promote and harness the RE resources of Nigeria and incorporate all viable ones in the national energy mix;
- to promote decentralized energy supply, especially in rural areas, based on RE resources;
- to deemphasize and discourage the use of wood as a fuel;
- to promote efficient methods in the use of biomass energy resources;
- to keep abreast of the international development in RE technologies and applications [18].

Table 11
Energy form and policies.
Source [53].

Energy form	Policies
Natural Gas (NG)	Utilize the nation's NG reserves into the energy mix More gas exploration Eliminate flaring by 2008 Encourage privatization
Oil	Increase refining capacity Endorse exploration looking for more oil reserves Derive more economic benefit from oil reserves Privatize the oil industry
Goal	Resuscitation of coal industry for export in an environmentally friendly manner
Tar Sands	Encourage tar sands exploration driven by the private sector Extract oil from tar sands
Nuclear	Pursue nuclear as part of energy mix
Hydropower	Fully harness the hydropower potential (in particular small-scale) through environmentally friendly means and through the private sector Promoting rural electrification through SHP
Solar	Help develop the capabilities to utilize solar energy
Wind	Help develop the capabilities to utilize wind energy
Hydrogen	Help develop local production capabilities for hydrogen energy
Biomass	Promote biomass as an alternative energy source
Fuelwood	Promote the use of alternative energy source to fuelwood De-emphasize fuelwood as part of the nation's energy mix
Other REs	Will remain interested in other emerging energy sources.

In its efforts, ECN has some made demonstration projects, depicted in Table 12, as part of the RE promotional activities.

In the struggle to boost the energy sector, in 2006, the Renewable Energy Master plan (REMP) for Nigeria was formulated as part of the African strategy on emission reduction [54], to address the challenges of moving towards clean, reliable, secured and competitive energy supply [55]. The objectives of the REMP are as follows [6]:

- To develop and implement strategies that will achieve a clean reliable energy supply and establish mechanisms to develop the sector based on international best practices, to showcase viability for private sector participation.
- To provide a comprehensive framework for developing RE that will ensure:
  - expanding access to energy services to Nigerians;
  - national agenda on emission reduction;
  - raising the standard of living, especially in the rural areas;
  - stimulating economic growth, employment and empowerment;
  - increasing the scope and quality of rural services, including schools, information, health services, entertainment, water supply and reducing the migration to urban areas [56].

In spite of recent efforts to reinvigorate the RE sector in Nigeria, the institutional framework is still feeble, and the following must be addressed to give RE the required impetus:

- detailed national energy mapping should be carried out to access actual RE potential in order to define realistic policy objectives that can aid the design element selection;
- introduction of a comprehensive standard and code of practice;
- enhancing the role of RE in the overall energy policy and the national energy mix;
- a well articulated RE research and development agenda over the coming years with decent funding;
- training of quality personnel at both technical and engineering levels in order to attain self-sufficiency;
- the integration of RE development with environmental factors and with energy efficiency.

Despite the abundant energy resources available in Nigeria, they have not been properly managed to satisfy the nation's energy needs. Government's over-dependency, and excessive fixation, on oil has slowed down the development of alternative sources of energy, even when the need is glaring.

4.2. Renewable energy target

A mandatory RE target is a government legislated requirement on electricity retailers to source proportions of total electricity sales from RE sources according to a fixed time frame. Many countries have targets that may extend for short, medium or long time. Brazil has 5% power production from RE. India has 4% power production from various RE sources; 1% from solar energy which amount to 1.3 GW and 211 GW from all other sources. Egypt has 10% RE production currently, and is expected to be doubled in the year 2020. Nonetheless, Nigeria has a 0% RE share currently and is targeting 7% in 2025 [22]. The development of RE technologies in Nigeria has been slow. New measures are aimed to boost growth in the energy sector (legislative framework, licensing arrangements for private-sector operators, Feed-in Tariffs and clarifying market rules for RE service and products). Rural electrification programs are supposed to take RE sources into full account. Liberalization of the energy sector, which took place in 2005, has led to private sector participation in the energy sector, and a number of operational Independent Power producers (IPPs) are operating in the country today. Establishment of off-grid generation/distribution plants is to be encouraged by the government through the offer of

- moratorium on import duties for RE technologies;
- design of further tax credits, capital incentives and preferential loan opportunities for RE projects;
- Feed-in Tariffs for SHP, solar and wind energy.

The projected energy demand for Nigeria is approximately 16,000 MW, 30,000 MW and 192,000 MW in the short, medium and long term basis respectively (at a 10% economic growth rate scenario). Based on this projection, RE electricity is expected to contribute about 13% in the short term, 23% in the medium term and 36% in the long term of the total energy and electricity supply as contained by the National Energy Policy [22]. The expected growth of RE resources is shown in Table 13.

Notwithstanding, the level of implementation to date has been very low and sluggish. An implementation plan is yet to be developed and no explanation has been given for the lack of implementation of the laudable policy. The country needs to learn from the experiences of other developed countries such as Japan, USA and emerging economics like the BRICS countries including China and neighboring South Africa. This will undoubtedly assist the GoN to put in place policies which enable a swift and consistent development of RE, and means by which the policies are implemented. National development plan should include detailed strategies and initiatives to drive the development of alternative sources of energy. Interdependencies in sub-sectors need to be taken into account in setting the goals and targets. All the policy measures put in place and implementation strategies to promote the use of the RE systems and practices can only be

Table 12
Pilot and demonstration projects.
Source: National Renewable Energy Master Plan (2009).

Technology	Applications	Capacity range	No
Wind generator	Village lighting	5 kW	1
Solar PV	Rural electrification, TV, health center, water pumping and telecommunications	0.88–7.2 kW	11
Solar dryer	Rice and forage dry	1.5–2.0 t	4
Hot water heater	Hospital hot water	800 l	1
Chick brooder	Chick brooder	100–200 birds	7
Biodigester	Production of biogas using cow dung, pig waste, chicks droppings, cassava peelings and human waste	10–30 m^3	6
Improved woodstove	Community promotion projects for cooking	80–200 persons per day	

realized with strengthened energy institutions. In this regard, there is a need to establish organizations or offices at states and local government levels that will be charged with the responsibilities of ensuring the full implementation of projects and programs of the ECN at the grassroots levels.

5. Effective policies for advancing renewable energy in Nigeria

In order to address issues related to realizing the vision of a competent RE blueprint, an integrated, scientific approach to the energy value chain, taking into consideration the significant interdependencies and synergies between the energy sub-sectors, must be applied. The following proposed supplementary policies may be necessary for Nigeria for the development of renewable energy, as with other developed nations.

5.1. Renewable obligation

The renewable obligation (RO) is the main support mechanism for renewable electricity projects in the United Kingdom (UK). Smaller scale generation is mainly supported through the Feed-in Tariff scheme (FiT). The RO came into effect in 2002 in England and Wales as well as Scotland and in 2005 in Northern Ireland [57]. It places an obligation on electricity suppliers to source an increasing proportion of the electricity they supply to customers from renewable sources. This is done through purchasing a Renewable Obligation Certificate (ROC) issued to an accredited generator for renewable electricity. It is a proof that a certain amount of electricity has been generated from an RE source.

It is of great benefit for Nigeria to borrow a leaf from these developed countries through the introduction of RO in the energy sector policy. ROCs ensure a certain minimum percentage of green energy is produced nationally and provide the financial incentive to encourage generators to invest in RE schemes of their own. The incentive received from ROCs will promote private investors to capitalize on RE development, since through the ROC; the renewable generator will have two sources of income. Income generated from the sale of electricity to the wholesale market, which does not distinguish between renewable and non-renewable energy, and from the sale of ROCs. Therefore, energy companies (just rising up) in Nigeria should be required to generate a minimum of 10% of their electricity from RE sources. If they have not managed to produce the required amount of green energy themselves, they must purchase ROCs on the market to make up the shortfall. Fines can be imposed for failure to buy the required amount. Thus, generation of electricity from RE will be, presumably, encouraged.

5.2. Feed-in-Tariffs

Feed-in Tariffs (FiTs) are one of the government strategies for providing financial support for RE generation in UK [58]. The aim of FiTs is to provide a simple system to incentivize small domestic and business renewables. FiTs are the most effective policy to encourage the rapid and sustained development of RE [59,60]. The scheme pays a tariff, which varies according to the technology and the size of the installation, for every kWh generated and the quality of resource. It also pays a small additional tariff for the lifetime of the scheme, which is linked to the retail price index [61]. Further details about the functions of FiT systems and the evaluation criteria of different design options are described in Refs. [58,62].

Table 13
Expected renewable energy growth in Nigeria.

Resources	Short	Medium	Long
Large hydropower	1930	5930	48000
Small hydropower	100	734	19000
Solar PV	5	120	500
Solar thermal	1	2	5
Biomass	1	100	800
Wind	1	20	40
All renewables	2038	6907	68345
All energy resources	16000	30000	192000
% of Renewables	13%	23%	36%

Renewable technologies have been on the rise worldwide through renewable energy FiTs. As of 2012, 65 countries have implemented some form of a FiT [59], driving 64% of global wind installations and 87% of the photovoltaic capacity that has been installed worldwide [63]. While the majority of these installations have occurred in industrialized countries, particularly in Europe, USA, and China, the African continent, and Nigeria in particular, still have significant untapped RE potential.

Some African countries like Kenya, Mauritius, Algeria, Tanzania, Rwanda, Egypt, Uganda and South Africa have introduced FiT. Ghana, Ethiopia, Botswana, Namibia and Nigeria are just developing or planning their FiTs. FiT policies provide a promising mechanism that can unlock RE development in Nigeria. It encourages investment in the generation of RE, from individual home owners and communities as well as big companies, by buying and paying made for all the electricity that is produced from renewable sources. FiTs are most successful when they are an integral part of a country's wider development strategy. Thus, high-level political support and strong buy-ins from civil society and the private sector are crucial factors for the successful development and implementation of the FiT. Therefore, Nigeria is encouraged to enact RO and FiT laws to facilitate private sector investment in RE for electricity generation as well as to boost investment security. FiT payment can be funded through budgetary allocations; largely from savings arising from petroleum subsidy removal.

5.3. Energy efficiency

Energy efficiency (EE) is a technological solution for eliminating energy losses in the existing system. EE refers to using less energy

to produce the same amount of service or useful output [64]. This can be carried out by the installation of EE technologies with the objective of reducing load levels in the long-run, while maintaining customer comfort or level of service [65]. Some of the examples of EE are replacement of incandescent light bulbs with compact fluorescent tubes [66], the use of automatic thermostats and identifying and repairing leaks in compressed air. The importance of EE as a policy objective is linked to commercial, industrial competitiveness and energy security benefits, as well as increasingly to environmental benefits such as reducing carbon dioxide emissions [64]. According to IEA, improved EE in buildings, industrial processes and transportation could reduce the world's energy needs in 2050 by one third, and help control global emission of GHG [67]. EE and RE are twin pillars of a sustainable energy policy [67], and maintain high priorities in the sustainable energy hierarchy. EE has a national security benefit because it can be used to reduce the level of energy inputs from foreign countries and may slow down the rate at which domestic energy resources are depleted.

EE has been discussed to be included in Nigeria's national RE policies. However, it has not been implemented at any level. The citizens of Nigeria should be educated on how to benefit from the advantages derived from adopting EE as it is done by developed countries. This could be achieved by utilizing improved materials over energy tariffs with incentives for certain consumption patterns, up to sophisticated real-time control of distributed energy resources [68].

The economy and people's quality of life should be developed using approaches that do not require increase in energy consumption through the application of EE. If the EE is effectively promoted at all levels, then the average annual growth in energy demand can be reduced. The use of a comprehensive policy will be necessary to promote EE in Nigeria. There should be a ban on the import, manufacturing and use of incandescent bulbs. Distribution side management should be targeted at ensuring efficiency in energy consumption at the electricity industry.

5.4. Hybrid-microgrid system

Rural electrification is a basic service required for development. Nigeria has a diverse geography which makes it intractable to supply electricity to rural communities through the national grid. RE has become an important alternative as a power provider in rural systems in supply side planning for microgrids [69]. Introduction of RE provides good opportunity for effective energy decentralization and security to both rural and urban citizens. This could be carried out through distributed generation, solar PV, wind, biomass, and the diesel operated hybrid-microgrid system.

A microgrid is a cluster of interconnected micro-sources that are referred to as distributed generations (DGs), loads and energy storage systems that cooperate with each other to be collectively treated by the grid as a controllable generator or load [70]. Hybrid systems are basically a combination of two or more different but complementary energy supply sources at the same site. Hybrid systems provide relatively constant electricity at an affordable cost, even when one of the supply systems is shut down.

Standalone solar PV or wind energy systems, do not produce usable energy for considerable portion of time during the year. This is due to variable sunshine hours as regards to solar PV, and relatively fickle cut-in wind speeds, resulting in underutilization of capacity [71]. The independent use of both solar PV and wind energy results in considerable over-sizing for system reliability. Typical hybrid systems include a conventional generator power by diesel, for example, and a renewable energy source(s) including solar PV, wind or both, and energy storage such as batteries if needed [71]. Autonomous hybrid microgrid systems can cater for the daily energy services, such as cooking and lighting, for the remote and impoverished rural communities in Nigeria.

While the previous proposed regulatory policies could further the RE deployment in the country, still, the GoN needs to take decisive initiatives in enhancing the development, deployment and application of RE resources and technologies in the national energy market. The incentives assigned for fossil fuel and subsidies on petroleum should be shifted to the development of RE, to make the technology affordable for low income earners.

Stimulatory measures to promote RE service provision among public and private investment are to be put in place as it is done in Egypt, Malaysia and South Africa. The stimulatory measures include

- adoption of a cost effective electricity tariff;
- encouragement of private sector participation. This could include
  - developing the necessary guidelines for power wheeling on transmission and distribution grids and approve the necessary tariff;
  - developing necessary contracts for public/private partnerships for service providers to encourage private sector to invest in solar energy, wind farms, small hydropower, etc.

Nigeria needs to promulgate strict energy polices to be enforced with adequate, earmarked funding so as to save the country from a possible energy crisis, that can render the rural dwellers in darkness in this modern age.

6. Prospects of renewable energy for rural energy provision

There are great opportunities for the use of RE technologies in applications, where electricity, thermal energy or mechanical power, are required. Such applications include non-thermal electricity generation, thermal power plants, industrial and domestic cooking and heating of liquid and gasses, standalone power systems and grid power supply; water purification, irrigation and potable water supply, lighting; drying and processing of agricultural products, etc. However, in view of certain characteristics of the energy sector in Nigeria and the attributes of the RE, in comparison to non-renewable energy and conventional energy, greater prospects for the use of RE exist in the rural sector of the economy.

Energy is an indispensable ingredient for the socioeconomic development and rapid urbanization. Modern economic activities depend predominantly on petroleum products and electricity. However, there is serious economic and demand capacity constraints in the extension of the latter sources from urban to the rural areas. Rural dwellers are famished, their energy demand levels are low and the center of demand is scattered. Only 18% of rural dwellers are exposed to electricity while almost 81% of the urban dwellers have access to it. In addition, while kerosene can be purchased in some urban centers at pump price, its retail price in rural areas is often higher [52].

Wind, solar PV and micro-hydro systems have proved more cost-effective on a lifetime basis, than grid electricity or diesel generators in situations where loads are low and away from the grid. The dotted nature and low power demand levels of rural load centers suggest the use of decentralized and small-scale power supply systems to which wind, solar PV and micro-hydropower and other RE power generators are adequately suited. Deliberate policies and programs are required to identify and implement the above concepts in rural areas that are unlikely to be grid connected in the long term (15–20 years). A sustainable project

implementation approach will require the joint participation of government, the private sector and consumers.

RE resources such as wind, solar PV, biomass and small hydropower (SHP) are, in general, well distributed over the country. The concept of Integrated Rural Village Energy Supply (IRVES) was established by the GoN to study the energy needs of rural communities for various socioeconomic activities, energy resources available to these communities, energy related environmental problems, as well as the skills and trainability of its manpower. An energy supply and consumption system for the community would then be developed, using the available energy resources, which are mostly RE ones, to meet the identified needs in a sustainable way. Capacity building programs and post-project management will be provided to enhance sustainability. Key features of the post-project management arrangements are provision for community participation in the management and payment, by beneficiaries, of centrally provided energy services, to cover operation and maintenance costs [18].

Widespread adoption of modern RE technologies, with the proper government support, can provide an excellent alternative to conventional firewood based technologies; used predominantly by rural dwellers. Large scale introduction of biogas technology and solar cookers including the use of coal briquettes, natural gas and kerosene can reduce the share of fuelwood in the energy mix [18]. This has the consequences of not only improving the living standard of the rural population in Nigeria, as far as the education, economic, and social aspects are concerned, but also decreasing exposure to indoor smoke pollution, associated with fuelwood burning, which pose chronic health problems. This would in turn decrease the mortality rate, in which Nigeria is among the highest in the world, and revamp the wellbeing of rural Nigerians.

7. Conclusions

A significant proportion of the Nigerian population is living in rural communities, located quite far off the nearest connection to the national grid. These rural communities have no proven deposits of natural gas, crude oil or large rivers, but are, however, blessed with abundant renewable energy (RE) resources. Apart from large hydro and conventional biomass, RE resources in Nigeria are presently not given any consideration in the country's energy supply mix and are even marginalized in future energy plans. Notwithstanding the fact that, Nigeria is generally blessed with ample conventional and renewable energy resources, the demand is significantly higher than the energy generated. Because of the abstruse inefficiencies associated with electric energy provision in Nigeria, it is increasingly harder for rural Nigerians to have access to the electricity service. This paper is advocating the use of renewable energy resources for closing the gap between energy demand and supply in Nigeria as well as improving the wellness of rural Nigerian communities. The potential of various RE sources, including large and small hydropower (SHP) systems, solar energy, wind energy, and biomass energy, were elaborated. National government policies formulated for the development of RE sources were outlined. Many of the Government of Nigeria (GoN) energy initiatives are merely green paper policies that lack the resolve to be taken into the implementation realm. Whereas it may be difficult to navigate the intricacies of Nigeria's energy governance tumult, a fine line of argument is straddled throughout this paper. By avowing that existing government policies are de rigueur, some new measures, that can meld well with these policies to reinvigorate them, were proposed. The adoption of RE technologies will unambivalently lead to a better allocation of energy resources among the population, which would in turn alleviate the misfortunes of the rural communities currently groaning under acute shortage of electricity. It will eventually ameliorate the energy outlook of Africa's most populous nation.

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